4.0 INDICATOR BACTERIA INPUTS TO GALVESTON BAY

The purpose of this section is to analyze and quantify to the extent practical the contribution of indicator organisms to Galveston Bay from a range of sources. The sources to be considered are:

- Permitted wastewater discharges,
- Wastewater collection system leaks, overflows and excursions,
- Partially treated wastewater from failed septic systems, and
- Runoff from watershed areas.

As can well be imagined, these categories frequently overlap with attendant analytical difficulties. The problem is compounded by the dynamic nature of indicator organism concentrations. While these problems exist, it is nevertheless worthwhile to attempt the quantification in that the results will at least bracket expected values and provide a measure of the relative importance of the various sources.

A major component of the analysis is based on a recently completed project for the Galveston Bay National Estuary Program, "Characterization of Non-Point Sources and Loadings to Galveston Bay", by Groundwater Services, Inc. (GSI) and Rice University (1991). Additional analyses are performed using data from the City of Houston as well as data from Harris and Galveston Counties (City of Houston, 1991). The reasons for employing the Houston data are:

1. Houston is by far the largest urban area in the immediate bay watershed,

2. The treatment plants and collection systems are generally representative of the other bay communities in terms of age and design,

3. Much of the data from the City are computerized and readily available, and

4. Over the last five years the City has made major investments in identifying and repairing problems in its collection system which allows quantification of these sources to some degree.

Each of the four major topics will be discussed, emphasizing the data available. The final subsection provides an integration of various components and data sources.

4.1 PERMITTED WASTEWATER DISCHARGES

This subsection addresses domestic/municiple wastewater treatment plants (WWTPs). While it is recognized that some industrial discharges do contain FC bacteria, often in the absence of any enteric wastes (see discussion in EPA, 1986; Dufour, 1977), these inputs are considered to be relatively small in the bay area.

The domestic WWTP category is perhaps the easiest to quantify in that all permitted point sources are required to report monthly information on discharges including average and daily maximum flows and minimum residual chlorine concentrations. So long as there is a residual of chlorine in the effluent after a minimum of 20 minutes contact time (at maximum flow, the actual contact time at normal flows is typically much longer), there are essentially no FC positive test results.

While it cannot be said that all treatment plants in the Galveston Bay immediate drainage area always maintain the required chlorine residual, it can be said that failures to do so are relatively infrequent. A similar statement can be made about the frequency of bypasses from treatment plants. These points are illustrated in Table 4-1 which is a tabulation of the number of bypass events and days when the minimum chlorine residual was not achieved during the one year interval of July, 1990 through June 1991. It can be seen that over the course of a year, thirty five plants (12,775 plant-days) had a total of six days when the chlorine residual was less than 1 mg/L. Only one of these observations actually had no chlorine residual.

Similarly, only one treatment plant bypass occurred during the year. Interestingly, this bypass occurred as a result of a failure in construction work being performed on the collection system. Rehabilitation work on Houston's collection system is ongoing in several areas and will be discussed in the next section. The bypass did not result from capacity limitations. This plant and the rest of the Houston system has capacity for over twice the actual wastewater flows.

4.2 COLLECTION SYSTEM LEAKS, OVERFLOWS AND EXCURSIONS

The City of Houston has portions of its collection system which are roughly 100 years old and large areas approaching their 50 year anniversary. As growth of the City occurred, the collection system has suffered from a combination of aging processes (soil settlement, acidic corrosion, etc.) and, with redevelopment of older areas, the addition of flows greater than what was originally expected when the sewers were designed. The result was overflows or releases from the sewers, particularly during wet weather and sometimes in dry weather.

Collection system problems include both undesired inputs and releases. Inputs include illicit stormwater connections and leaks which allow entry of stormwater during wet periods. These are a concern because they result in dramatically higher sewer flows which can exceed the capacity of lines, lift stations or the receiving treatment plant. When any of these occurs, a bypass results. Releases can also occur from leaks which enter the soil

TABLE 4-1

TABULATION OF HOUSTON WASTEWATER

DISINFECTION AND BYPASS PERFORMANCE

City of Houston Plant	Number of Min Cl_2<1.0	Number of Bypass Events
Sims Bayou	0	0
Sims South	2 (0.8, 0.0)	0
Almeda Sims	1 (0.8)	0
Chocolate Bayou	0	0
Clinton Park	0	0
FWSD-23	0	0
Gulf Meadows	0	0
Homestead	0	0
West District	0	0
Southwest	0	0
WCID-47	0	0
WCID-51	0	0
Easthaven	0	0
FWSD-34	0	0
Sagemont	0	0
Southwest	2 (0.4, 0.3)	0
Northest	0	0
Intercont. Airport	0	0
Southeast	0	0
Eastex Oaks	0	0
69th Street	0	1 (7 MG)
WCID-111	0	0
White Oak	0	0
Northgate	0	0
Imerial Valley	0	0
Harris Co. MUD-123	0	0
Harris Co. MUD-139	0	0
Turkey Creek	1 (0.5)	0
Green Ridge MUD	0	0

TABLE 4-1 (Concluded)

City of Houston Plant	Number of Min Cl_2<1.0	Number of Bypass Events
Beltway	0	0
Cedar Bayou	0	0
Northborough	0	0
Harris Co. MUD-218	0	0
Keegans Bayou	0	0
Westheimer Road	0	0

Source: TWC printout 07/90 to 06/91

or connect with the storm sewer system without the effect of higher wet weather flows. Significant leaks of this type are much less common and more readily identified and fixed than wet weather overflows, but also have the capacity to have a readily detectable impact on receiving waters. Leaks to the soil which do not enter a stormsewer could in some cases enter surface waters in a way that would be difficult to detect.

Elimination of overflow points is the culmination of extensive work in monitoring flows and water levels in various portions of the system during wet weather, using these data to allow numerical modeling of the system for design conditions, using the numerical model to determine the most appropriate remedy, design of the selected remedy and construction. This is a slow and expensive process (hundreds of millions spent to date and several billion still to go). It is also one that will never be complete as collection systems continue to age.

The City of Houston has been heavily involved in work on its collection system for many years. Since 1987, the City has been reporting activities biannually to the TWC in documents called "Response Reports". In the September 1991 Report, approximately 140 overflow points were reported as eliminated. Of these, only three are reported as class A or which release during dry weather.

In addition to the work being performed by the main engineering effort of the City, the Wastewater Quality Control group has been monitoring water quality conditions in the major bayous and has identified a number of dry weather sewer releases. An important element of this work, in addition to identifying some additional leaks, was that an attempt was made to measure the flows and quality of the observed discharges.

Table 4-2 lists measured flows and water quality data (provided by Glanton, 1992) from a number of leak points monitored in the Buffalo Bayou watershed from the upper end to a point just outside of downtown (Shepherd), an area that includes some fairly old sections as well as newer ones and does not have the atypical age and density of downtown Houston. Each of these observations is from a storm sewer near Buffalo Bayou during dry weather conditions. Attention was first attracted to these locations by monitoring of coliform levels in Buffalo Bayou. A sharp increase in bayou FC levels was an indication of a sewer leak. City personnel then searched the connecting storm sewers in the area until one was found to be flowing. The flowing storm sewer was then traced until the leak was detected. Once identified, the leak was turned over to City maintenance crews for repair. The data in Table 4-2 includes observations both before and after repair.

Several observations can be made on the data in Table 4-2. The first is that a fairly small percentage exhibit the numerical characteristics of raw sewage (CBOD > 100 mg/L, NH_4-N of around 10 mg/L or greater, and coliform levels > 10^6 FC/dL). Using these criteria, only the observations at Shepherd on 3/29/89 and Adams Gully on 4/06/89 would appear

TABLE 4−2
CITY OF HOUSTON SEWER LEAK MONITORING DATA

LOCATION DATE	ID #	FLOW (GPM)	pH	NH_4-N	NO_3-N	TKN	CBOD	FC / dL*
RUMMEL CREEK								
07/17/90	OT−418	50.0	7.7	1.1	1.2		3.1	53,000
08/13/90	OU−389	200.0	7.9	0.1	0.5		3.9	1,600
11/05/91	1Y−162	0.0	8.0	0.1	0.2	0.5	1.5	270
	AVERAGE	125.0	7.9	0.4	0.6	0.5	2.8	2,840
FONDREN								
07/30/89	9R−354							220,000
08/25/89	9S−163		7.7	0.1	0.7		50.4	2,000,000
08/13/90	OU−390	100.0	8.2	2.1	0.7		12.7	3,000,000
08/21/90	OU−562							150,000
09/04/90	OW−157							21,000
10/03/90	OX−183	40.0	8.2	1.8	0.6	2.0	2.8	13,000
11/05/91	1Y−163		7.9	0.1	0.3	5.0	18.0	78,000
	AVERAGE	70.0	8.0	1.0	0.6	3.5	21.0	170,660
BERING DITCH								
04/06/89	90−45							4,300
10/23/89	9U−377							1,400
02/22/90	OM−200							85,000
04/17/90	OP−104							3,100,000
05/07/90	OR−21							8,000
07/17/90	OT−420	100.0						32,000
08/13/90	OU−391	400.0	9.5	0.1	1.3		10.8	2,000,000
08/21/90	OU−564							22,000
11/20/90	OY−256							42,000
12/06/90	OZ−177	80.0						21,000
03/07/91	1N−131	850.0						370,000
03/20/91	1N−154	850.0						TNTC
03/25/91	1N−163	850.0						320,000
04/10/91	1P−178	778.0	9.0	0.0	0.3		4.9	2,900
11/04/91	1Y−156	800.0	8.6	0.4	0.4	0.8	3.0	1,500
	AVERAGE	588.5	9.0	0.2	0.7	0.8	6.2	36,724
FARTHER POINT	120"							
10/23/89	9U−380							8,400
04/18/90	OP−114							3,600
08/16/90	OU−464	30.0	7.9	0.2	3.9	4.6	3.7	41,000
11/20/90	OY−263							1,100
11/05/91	1Y−164		8.2	0.1	0.7	0.9	2.9	3,700
	AVERAGE	30.0	8.1	0.2	2.3	2.8	3.3	5,503
SPRING BRANCH								
10/10/89	9U−263							4,700
02/06/90	OM−59							4,700
11/07/91	1Y−175		8.8	0.5	1.7	1.3	1.6	720
	AVERAGE		8.8	0.5	1.7	1.3	1.6	2,515

TABLE 4–2
CITY OF HOUSTON SEWER LEAK MONITORING DATA (CONTINUED)

LOCATION DATE	ID #	FLOW (GPM)	pH	NH_4–N	NO_3–N	TKN	CBOD	FC / dL*
ADAMS GULLY								
03/08/89	9N–67							130,000
03/20/89	9N–114		6.9	0.5	1.2		15.6	590,000
03/22/89	9N–132							93,000
03/27/89	9N–184							376,000
04/06/89	90–78		7.9	17.3			19.8	
04/19/89	90–134			6.0				2,100,000
05/26/89	9P–222		8.1	1.6	1.1		6.0	
07/13/89	9R–117			0.7	1.3		2.7	2,000,000
02/02/90	OM–21							3,300
03/23/89	ON–166							1,400
10/30/90	OX–301							8,900
05/02/91	1R–9	636.0	8.1	1.1	0.9	1.0	3.7	6,800
11/04/91	1Y–157		8.1	1.3	0.5	2.2	12.0	910
	AVERAGE	636.0	7.8	4.1	1.0	1.6	10.0	47,636
BRIARHOLLOW								
03/20/89	9N–120		7.7	0.5	0.9		12.7	140,000
05/23/90	OR–144		8.0	3.1	0.4		118.0	TNTC
05/30/90	OR–186							2,000,000
07/17/90	OT–421	50.0						9,400
08/16/90	OU–465	50.0	7.7	0.2	1.2	4.7	2.8	4,100
10/03/90	OX–185	60.0						44,000
10/30/90	OX–300							5,900
03/20/91	1N–155	150.0						24,000
03/25/91	1N–164	150.0						3,100
11/05/91	1Y–165		7.8	0.3	0.7	7.0	28.0	TNTC
	AVERAGE	92.0	7.8	1.0	0.8	5.9	40.4	25,994
SANDMAN								
04/06/89	90–69	15.0						110,000
04/24/89	90–193	150.0						TNTC
05/23/89	9P–205							520,000
10/03/90	OX–184	15.0	8.5	0.2	2.7	1.4	1.5	940
10/30/90	OX–308							1,600
05/07/91	1R–155	10.0	7.6	6.3	0.4	6.9	7.6	90,000
11/07/91	1Y–176		8.4	2.4	2.6	4.7	2.9	16,000
	AVERAGE	47.5	8.2	3.0	1.9	4.3	4.0	22,327
SHEPHERD								
03/29/89	9N–189	50.0	7.8	16.5	0.8		53.0	TNTC
03/23/90	ON–167	5.0						740
10/30/90	OX–309							23,000
11/07/91	1Y–177		8.4	0.6	2.0	3.1	8.4	12,000
	AVERAGE	27.5	8.1	8.6	1.4	3.1	30.7	5,889

TABLE 4-2
CITY OF HOUSTON SEWER LEAK MONITORING DATA (CONTINUED)

LOCATION DATE	ID #	FLOW (GPM)	pH	NH_4-N	NO_3-N	TKN	CBOD	FC / dL*
WILLOWICK								
03/08/89	9N-70							7,400
03/30/89	9N-197							1,740,000
04/03/89	90-18	80.0						1,600
04/24/89	90-182							TNTC
05/24/89	9P-211							52,000
07/13/89	9R-115			0.2	1.8		3.8	5,200
10/02/89	9R-26							9,600
02/12/90	OM-103							450
03/24/90	14							250,000
05/23/90	OR-145							2,700,000
07/17/90	OT-422	100.0						250,000
08/09/90	OU-313	120.0	8.3	0.1	1.3	0.9	3.4	6,900
10/01/90	OX-177	60.0						14,000
10/30/90	OX-303							34,000
04/10/91	1P-177							8,900
05/02/91	1R-8	219.0	7.8	1.6	0.8	7.2	6.4	810,000
05/14/91	1R-170	274.0						3,800
08/27/91	1R-228							6,600
10/02/91	1X-154	275.0	7.6	0.2	1.2	0.8	3.0	83,000
11/04/91	1Y-158		7.9	2.6	0.2	4.8	10.0	TNTC
	AVERAGE	161.1	7.9	0.9	1.1	3.4	5.3	28,919
OVERALL AVERAGE		237.4	8.1	2.1	1.1	3.1	13.4	16,086

* CALCULATIONS ARE OF GEOMETRIC MEAN WITH 1 dL = 100 mL

to be raw sewage and even in these cases the CBOD values are well below 100 mg/L. On the other hand, there are a larger group of observations which have FC levels in excess of one million counts per dL.

Several possible explanations are proposed which may be playing a role in the observations. The first is that a substantial portion of the leaks into the stormwater system may be freshwater. This would have the effect of diluting the wastewater chemical characteristics and also explain why in some cases there was still flow after the known sewer leak was repaired. A second factor may be the treatment effect which occurs during wastewater's flow down the stormsewer to the sampling point. During dry conditions, wastewater would have substantial time in what amounts to a linear trickling filter treatment plant. However, without disinfection at the end of the hypothesized treatment plant, FC levels would still be quite high. Another factor is that wastewater which leaves the sanitary sewer and reaches a storm sewer will have a substantial opportunity for settling of solids in the sanitary sewer. The sewage which reaches a storm sewer will thus be substantially weaker in strength than raw wastewater.

Whatever the explanation for the difference from the expected characteristics of raw sewage, it is submitted that these data are the best available to characterize the effect of collection system leaks under dry flow conditions. With a total of ten locations identified, the average of each flow measurement per location was computed. This was 237.4 gpm. The total of the average dry weather releases were 1,779 gpm. The geometric mean FC concentration was computed from the data available for each site. The geometric average of the site geometric means was 16,086 colonies/dL, with a range from 2,840 to 170,660. With the sewer service area of Buffalo Bayou between Addicks and Shepherd approximated by the difference in the two watershed areas (358 at Shepherd and 293 at Addicks or 65 sq mi), an estimate of dry weather FC input from sewer leakage per day per sq. mi. of sewered area can be derived.

1,779 gal/min/65 sq.mi. * 37.85 dL/gal * 1,440 min/day * 16,086 FC/dL = 2.4 E 10 FC/sq.mi./day

To the extent that this area is representative of other sewered areas around Galveston Bay, a rough quantification of dry weather sewer leak inputs of indicator bacteria is possible.

The City also maintains records of pump station excursions. These are estimates of releases which occur from events such as extremely high flows, mechanical breakdowns or power losses (which are generally associated with extreme storm conditions). Records provided by the Wastewater Quality Control branch include events for the years 1989 through June, 1991. The data included with each event the date, duration and estimated volume based on the size of the lift station and duration. The duration was determined through records of pump downtime and/or water level in the wet well. Over the thirty month period, approximately 500 individual events were monitored. The total release volume for 1989 was 52.8 MG, for 1990 12.2 MG and for the first six months of 1991, 26.0 MG. A high proportion of these events were associated with very wet periods (May 17-18 '89, 7"-13" of rain; June 23-28,'89, Tropical Depression Allison; August 1,'89, Tropical Storm Chantel). With 1990 being considerably dryer than 1989, the amount of lift station overflow was much smaller.

To provide a basis for projecting the Houston data to the entire bay, the entire cumulative monitored lift station flow of 91.0 MG is divided by the City's collection system area (536.3 sq. mi.) and number of days in the record (912) to yield an average daily lift station release per square mile of service area of 186 gallons/day/sq.mi. This flow is primarily stormwater mixed with some smaller proportion of sanitary sewage. The exact proportion will vary considerably but will probably be at least five parts stormwater to one part sewage. It is not uncommon for treatment plants to encounter storm inflows of six to ten times dry weather flow. To estimate the FC loading from lift station excursions requires an estimate of the FC concentration of this water. CoH personnel have sampled raw, dry-weather sewage on a number of occasions. The average of these FC observations is 10^7 col/dL (Garrett, 1992). With this value, an estimate of stormwater diluted sewage of 500,000 col/dL would seem quite conservative. Using this value, an excursion estimate is:

186 gal/sq.mi./day * 37.85 dL/gal * 500,000 col/dL = 3.52 E 9 col/sq.mi./day

On a per year basis, this would be 1.28 E 12 col./sq.mi./yr.

While lift station excursions during wet weather are a significant contributor, they are by no means all of the wet weather overflow points. Over the last seven+ years, many modifications and improvements have been made to eliminate or greatly reduce overflows. However, due to the nature of these points, it is very difficult to quantify total annual release volumes. The City does not maintain a database of other overflow point releases, and there is no way that these could be quantified within the constraints of this project without such a database.

For comparison, another estimate is derived from a study of nonpoint source loads to the Houston Ship Channel (HSC) watershed conducted for the TWC in the mid-1980's by Winslow and Associates in conjunction with Alan Plummer and Associates (WAI, 1986). This study calculated loadings to the HSC of a range of conventional pollutants (but no indicator bacteria) for urban runoff, sewer overflows, and wet weather WWTP overflows The basic finding of the study was that urban runoff contributed the great majority c oxygen demanding load to the HSC, and that overflows accounted for about 10% of th CBOD and 5 to 6% of the load for other conventional parameters.

While the WAI study did not quantify indicator bacterial loads, it did estimate loads from sanitary sewer wet weather overflow events. The calculations were based on 163 identified potential overflow points, a probability of an overflow given a rain event, and a number of rain events per year to yield a calculated 8,188 overflows per year within the 825 sq. mi. HSC basin. These values would indicate that each identified location overflowed 50 times per year. The calculated flow from each location was 121,614 cubic feet, 0.91 MG or 3,444 cubic meters per event.

Event mean concentrations (EMCs) reported for overflow sampling events suggests that stormwater accounts for the majority of the overflow volume. For example, the $CBOD_5$ EMC was 48.5 mg/L and the NH_4-N was 3.83 mg/L, on the order of 3-5 times higher than urban runoff and much lower than wastewater. To estimate the FC loading from this overflow volume, the same conservative concentration of 500,000 col/dL used for lift station excursions will be employed. The estimated indicator bacteria loading from wet weather sewer overflows in colonies per sq. mi. per year is:

8,188 events/yr * 3,444 m^3/event * 10,000 dL/m^3 * 5 E 5 col/dL / 825 sq. mi. = 1.71 E 14

On a per day basis this is 4.7 E 11. Comparing this to the dry weather estimate above, it is about 20 times greater, as would be expected.

4.3 SEPTIC SYSTEM FAILURES

To date, very little work has been done in quantifying either the volume or characteristics of partially treated wastewater from failing septic systems. A rough, very conservative and heavily qualified estimate is developed here based on discussions with Galveston and Harris County personnel involved in septic system regulation and tabulations of the number of shoreline systems.

Before reviewing the information obtained, a brief definition of terms is provided. A typical septic or subsurface disposal system consists of a tank or tanks in series followed by a subsurface drainfield. Household wastewater first enters the septic tank where solids settling and anaerobic decay are provided. Water leaves the septic tank through baffles (to avoid solids carryover) and enters the drainfield where it seeps into the ground. If for some reason, the drainfield becomes clogged, this water will back up to the surface. The amount of this partially treated water that leaves the property will depend on the degree of blockage and soil moisture conditions.

The quality of such partially treated wastewater can be expected to be highly variable due to differences in septic tank detention time (function of tank size, solids accumuation in the tank and loading rate) and the amount of soil that the water passes through or over before it enters surface waters. Soil type can also be an important factor. Coarse sandy soils can allow water to move off the site and to the surface with little detention time or treatment. On the other hand, overland flow through vegetated soils can provide very good treatment similar to a land application wastewater treatment system. However, even if septic wastewater is actually well treated before it reaches the bay (except for facilities directly on the bay) the effluent on the surface produces unacceptable nuisance and public health considerations.

In discussions with the Harris County Sanitarian's office, some rough estimates of the number of septic systems and system problems were discussed. The County began issuing permits for new subsurface disposal systems in 1978. Since that time there have been approximately 13,000 permits issued. However, this is only a portion of the total number of systems in the County. A substantial number of systems existed prior to 1978, and a substantial number still exist in incorporated areas of the County. County personnel estimated that the total number of septic systems in Harris County was on the order of 100,000.

Currently the Sanitarian's office receives between 30 and 45 complaints per month regarding subsurface systems. Of these, 25 to 30 typically involve some type of violation. A violation in this context means water is coming to the surface in some fashion. This might be an easily observable flow off of the property or just a small ponded location on the property. Of the 25 to 30 violations, roughly 5 to 10 involve only washing machine discharges which are not hooked into the septic system. Using these ranges, the actual number of sanitary waste releases to the surface observed by Harris County is thus in the range of 15 to 25 per month. Most of these are corrected in short order but some remain unfixed for some time due to various reasons. Because these reported violations may not include all septic system problems, the upper end of all ranges is employed. Using 25 failures per month and 100,000 total systems gives a rate of 0.025% per month that would result in some release of water to the surface.

Harris County also has performed some visual inspections in unincorporated areas. In the northeast portion of the county which includes several hundred thousand residences, some of which are sewered and some not, inspectors found a total of 1,922 instances where leakage might be occurring. These instances ranged from directly observed water flowing from the ground into an adjacent ditch to simple vegetation changes indicating a possible leak. Some of these leaks or possible leaks could have involved either potable water lines or sewer lines so it is impossible to draw firm conclusions. However, it does suggest that the number of marginal septic systems might be higher than the number reported through the complaint mechanism. The county representative also noted that the majority of the 1,922 instances were observed in a few specific areas in northeast Houston which were old and had very high population densities on small lots.

Galveston County Health District (Entringer, 1992) estimates there are approximately 4,500 structures in Galveston County served by septic systems, 95% of which are single family residences. According to Mr. Entringer, the County has investigated approximately 70 complaints since October of 1990, a period of 15 months. With a monthly rate of 4.67 complaints and 4,500 systems, this amounts to a monthly rate of 0.1% per month, not greatly different from the 0.025% rate estimated for Harris County. Entringer also notes that of the 70 complaints, very few "discharged wastewater directly in Galveston Bay or its tributaries".

Another important aspect in dealing with failing septic systems is that with the very small flows involved, any release located away from the immediate bay itself would, under dry weather and low flow conditions, be substantially degraded before it reached the bay. Under wet conditions, the small flows would render the release undetectable in the much larger volume of runoff, which generally has a substantial indicator bacteria concentration. Accordingly, only septic systems directly fronting on the bay are considered.

Septic systems close to the bay were tabulated by the TDH in their Sanitary Surveys of Galveston and West Galveston Bays (1988). A count of the systems identified in these reports yielded 5,275 in Galveston Bay and 2,893 in West Galveston Bay, for a total of 8,168 near-bay systems. While it is recognized that many of these residences are only occupied seasonally, it will be assumed that they are all in use year round. Taking the upper rate observed in Galveston County of 0.1% per month would indicate that at any one time, roughly eight systems will be having a problem of some type sufficient to produce a complaint. While Entringer notes that very few of the complaint systems actually release wastewater to the bay, it will be very conservatively assumed that each releases water at a typical single family wastewater flow rate of 150 gallons/day. To simplify and allow quantification of a very conservative estimate, it is also assumed that the water released is raw sewage with an FC concentration of 2 E 6 col/dL, rather than the much lower value one would expect after anaerobic decay in a septic tank. With these very conservative assumptions, a septic tank coliform loading estimate is:

8 systems * 150 gal/day/system * 37.85 dL/gal * 2 E 6 col/dL = 9.1 E 10 col/day

On a per year basis, this would be 3.3 E 13 colonies which could, with worst-case assumptions, reach the bay. Even with the very conservative assumptions, this source will be shown to be quite small relative to other sources.

4.4 RUNOFF INPUTS OF FC BACTERIA

Groundwater Services, Inc. (GSI) and Rice University conducted a characterization of non-point source (NPS) loadings to Galveston Bay. Their objective was to conduct a geographic analysis and priority ranking of possible non-point sources and loads to

Galveston Bay. The primary elements for the non-point analysis included watershed hydrology, load estimates, ranking of subwatersheds, upper watershed influences, and mapping. The following is a summary of the non-point source loadings of FC to Galveston Bay developed by GSI.

The study on NPS loadings to Galveston Bay performed by GSI started by dividing the entire drainage basin of Galveston Bay into 21 watersheds based on drainage and topographic characteristics. These watersheds were further divided into 100 subwatersheds based on major watershed boundaries, subwatershed size, USGS watershed boundaries, and land uses. A watershed was defined as the drainage of a major stream flowing into Galveston Bay, and a subwatershed was a smaller area with generally uniform land use characteristics encompassing the vicinity of a tributary to a major stream.

Land use information was established and categorized by GSI based on interpreted satellite imagery. Their study found the following landuse distribution for the Galveston Bay drainage area below lakes Livingston and Houston: 10% high-density urban, 9% residential, 23% open/pasture, 22% agricultural, 1% barren, 15% wetlands, 1% water, and 18% forest areas.

Event mean concentrations (EMC), were estimated from a variety of local and nationwide data sources. The major sources for EMC data were the Rice University NPS Studies, the USGS Houston Urban Runoff Program Data, and the Texas Water Commission/Winslow Associates Houston Ship Channel NPS Study. Other sources included data from the EPA Nationwide Urban Runoff Program (NURP), the Priority Pollutant Survey from the NURP Program, the USGS Austin NPS study, and various agricultural NPS studies. FC EMCs employed by GSI were:

Land Use Category	FC EMCs (colonies/dL)	Relative Accuracy
High Density Urban	22,000	Good
Residential	22,000	Good
Agricultural	2,500	Fair
Open/Pasture	2,500	Fair
Barren	1,600	Fair
Wetlands	1,600	No Data
Water	0	No Data
Forest	1,600	Good

With these EMC values, three rainfall cases were formulated and the total NPS loads associated with each case were computed. The rainfall amounts from the three cases (an average year, a wet year with a 10-year return period, and an individual storm with 4.5 inch uniform rainfall) were transformed into runoff using the Soil Conservation Service method (SCS, 1986). The computed NPS loading of FC for each of the three cases are:

Case	FC Loads to Bay (*E15 colonies)
1. Average Year	355
2. Wet Year	531
3. Individual Storm	55

In addition, the computed NPS load of FC from each land use for the average year (case 1) are:

Land Use Category	FC Loads (*E15 colonies)
High Density Urban	208
Residential	101
Agricultural	18
Open/Pasture	17
Barren	0
Wetlands	4
Water	0
Forest	7

As for the spatial variation of the NPS loadings of FC, the computed coliform (and other substance) loads associated with the case 1 average year are listed in Table 4-3, which is Table 7.1c reproduced from the GSI report.

Several conclusions were drawn by GSI from this study. The first was that the precise sources of NPS loads were relatively difficult to determine due to their widespread, diffuse nature. The second was that the results from the three cases indicated that a significant portion of the annual loads occurred during a few of the largest rainfall events during the year. The third conclusion was that high density urban land use areas were the main contributor of NPS loads to the bay. For FC, this land use category contributed 59% of the total annual NPS loads from all categories. The last conclusion from this study was that the highly urbanized areas in Houston, Baytown, Texas City, and Galveston showed the highest loads per unit area for FC.

TABLE 4-3

AVERAGE YEAR TOTAL NON-POINT SOURCE (NPS) LOADS PER AREA BY WATERSHED

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Watershed	Area (sq mi)	Runoff Volume (thousand acre-ft)	Total Suspended Solids (kg/ha)	Total Nitrogen (kg/ha)	Total Phosphorus (kg/ha)	Biochemical Oxygen Demand (kg/ha)	Oil and Grease (kg/ha)	Fecal Coliform (bil. col/ha)	Dissolved copper (1/1000 kg/ha)	Pesticides (1/1000 kg/ha)
			NPS Loads by Unit Area							
Project Area	4,238	3,010	438	5.85	1.0	24.0	12.9	323	9.9	0.7
Addicks Reservoir	134	82	618	5.60	1.0	19.7	10.7	264	9.0	0.6
Armand/Taylor Bayou	77	70	584	8.41	1.4	34.1	25.5	564	12.8	1.1
Austin/Bastrop Bayou	213	121	380	4.44	0.8	16.1	4.2	158	8.0	0.4
Barker Reservoir	122	71	**1,022**	5.73	1.0	18.2	6.7	182	8.6	0.4
Brays Bayou	127	147	867	12.30	2.3	50.0	**50.6**	**1,018**	17.0	1.9
Buffalo Bayou	105	116	795	12.40	2.4	51.2	46.7	1,008	16.4	1.9
Cedar Bayou	211	153	469	5.86	1.1	22.5	6.3	230	10.5	0.5
Chocolate Bayou	170	95	434	4.27	0.8	14.3	2.9	125	8.0	0.3
Clear Creek	182	138	474	6.39	1.1	25.1	14.4	346	10.7	0.7
Dickinson Bayou	101	60	317	4.97	0.8	19.7	7.2	222	8.5	0.5
East Bay	288	193	348	5.21	0.9	21.0	6.1	223	9.1	0.5
Greens Bayou	209	184	559	9.20	1.7	38.9	25.4	630	13.0	1.2
North Bay	25	25	621	10.06	1.8	41.6	33.9	740	14.6	1.4
San Jacinto River	68	65	454	7.12	1.2	30.7	13.2	391	11.4	0.8
Ship Channel	166	198	787	11.56	2.1	47.3	44.6	914	16.5	1.7
Sims Bayou	93	91	660	9.76	1.7	39.6	32.2	697	14.4	1.3
South Bay	78	68	503	6.87	1.2	27.8	30.5	572	10.5	1.1
Trinity Bay	317	225	312	4.34	0.7	18.0	3.4	151	8.6	0.4
Trinity River	**1,099**	**572**	217	3.08	0.4	15.0	1.9	95	7.4	0.3
West Bay	344	212	335	4.55	0.8	18.0	9.6	237	7.9	0.5
White Oak Bayou	110	128	840	**12.78**	**2.4**	**52.5**	46.9	1,012	**17.1**	**1.9**
Median	134	121	503	6.39	1.1	25.1	13.2	346	10.5	0.7
Maximum	1,099	572	1,022	12.78	2.4	52.5	50.6	1,018	17.1	1.9
Minimum	25	25	217	3.08	0.4	14.3	1.9	95	7.4	0.3

Note:

1. Boldface/underline indicates highest watershed load for the parameter.
2. Source: Non-point source characterization Project. GSI. 1991.

One limitation of the study is the lack of information on the FC inputs from wetland areas. The GSI study employed an EMC of 1,600 col/dL, the same as for barren land and lower than agricultural or open land. While there has been little monitoring effort directed at FC concentrations from wetland areas, TDH personnel report that bay waters adjacent to wetland areas show rapid increases in FC levels following even moderate rains (Wiles, 1992). Similar observations and documentation were presented for tidal wetlands in Jensen, et. al. (1980). It is believed that had a more representative EMC been employed (higher than agricultural land), the relative contribution of wetlands to the baywide FC load would be more accurately portrayed. However, this would still undercount the actual contribution of wetlands to observed bay FC levels, simply because of their proximity to the bay relative to urban land areas.

4.5 DISCUSSION AND ANALYSIS

Comparing numbers on the urban loadings, it is reassuring to find some measure of agreement and some indication of progress. The agreement observed is between the calculated wet-weather load from the TWC/WAI study, using a perhaps generous FC EMC of 500,000 col/dL, and the GSI urban areal FC load. As calculated earlier using the WAI base, the areal load was 1.7 E 14 col/sq.mi./yr. The urban areas of Houston, represented by Brays and Buffalo bayous have areal loads of on the order of 1 E 12 col/ha per average year (Table 4-3). Converting the hectares to square miles yields 2.59 E 14 col/sq.mi/yr, in close agreement with the WAI-based value. This should not be considered too surprising since the GSI calculation was based in part on WAI and other data collected during a similar period.

The indication of progress is that current wet-weather loads, based on the lift station excursion data, are on the order of 1.3 E 12 col/sq.mi./yr, roughly two orders of magnitude less. While lift stations are certainly not the only wet-weather overflow points remaining, they are one of the major places where extreme flows can escape. At some point in the future, these should be the only major wet-weather overflow points for precipitation events which do not exceed the collection system design criteria. The dry-weather FC loads are smaller still by roughly two additional orders of magnitude.

Based on the data developed, treatment plants operating normally are not a significant source of FC bacteria. While treatment plant bypasses do occur, based on the Houston sample, they do not occur with sufficient regularity or magnitude to warrent quantification. Overflows and other collection system releases will continue to be a significant wet weather source, but the data available suggests that it will be considerably less in the future than was quantified in the GSI/Rice study using mainly data from the early 1980s.

Inputs from malfunctioning septic systems will be detectable only in the immediate locale and then only during wet weather when other sources will likely dominate. For example, the very conservative (probably by several orders of magnitude) estimate of near-bay failing septic system inputs, is roughly 500 times smaller than GSI's calculated inputs from agricultural land alone. While septic system contributions of indicator bacteria to the bay are undoubtedly insignificant relative to other sources, they still pose nuisance and public health concerns and have the potential to infect shellfish in the immediate vicinity of the system. The fact that septic systems appear to be a minor contributing factor should not be taken as a justification for reduced monitoring or problem correction efforts.

Based on the above discussion, EH&A believes that the GSI calculated FC load to the bay, which implicitly incorporates all of the sources discussed, is approximately correct. EH&A has only two reservations about this calculated load. One is the EMC value employed for urban and residential areas. This was developed from data collected at a time when bypasses and overflows in the Houston area may have been worse than they are today. On the other hand FC concentrations in urban/residential runoff are substantial even when an area is new and presumably has a tight collection system. Also, collection system work in other communities around the bay has not been nearly as extensive as in the Houston area. The second reservation is that the EMC value employed for wetlands is substantially lower than is actually the case. However, these are nothing more than reservations with no quantative basis for changes. Given the next point, there is little to be gained by refining the GSI FC loads.

While a quantification of indicator bacteria input to surface waters is a useful exercise, it is only part of the total picture. This is because coliform bacteria generally die off rapidly when introduced to surface waters (Mitchell and Chamberlain, 1974; Bellaire, et. al, 1977; Thomann and Mueller, 1987). The die off can reduce very high levels in the immediate vicinity of a wash off point to normal background levels in a matter of days.

In addition, FC inputs into many tributary streams may never reach Galveston Bay. This is particularly true in the highly urbanized streams of the Houston area feeding into the Houston Ship Channel, which provides a relatively long residence time before entering the bay. In short, while calculated FC loads to the bay are large, high concentrations in the bay tend to be localized and of short duration. This phenomona is illustrated by the TDH management plan for the conditional areas of Galveston Bay. These areas are closed following heavy rains (or high Trinity River inflows) but are reopened in a relatively short time, determined by post-rain monitoring.

The difference between actual data and calculated concentrations based on wash off inputs, without considering die off and hydraulic factors can be appreciated in Table 4-4. This table compares the average year FC runoff-based concentrations (from Table 7.1b of the GSI report) with actual geometric mean FC data for various areas where comparable segment definitions exist. It can be seen that reasonably similar FC concentrations exist for the two methods on some of the Houston area bayous. For example, the geometric

TABLE 4-4
COMPARISION OF MEASURED FC LEVELS AND
FC CONCENTRATIONS CALCULATED FROM RUNOFF

Watershed*	Area* (sq. miles)	Runoff* Volume (thousand acre-ft)	Calculated* Average FC Concentration (col/dL)	Measured Long Term** Geometric Mean FC (col/dL)
GBNEP	4,238	3,010	9,576	---
Addicks Reservoir	134	82	9,122	---
Armand/Taylor Bayou	77	70	12,991	35
Austin/Bastrop Bayou	213	121	5,858	79
Barker Reservoir	122	71	6,557	---
Brays Bayou	127	147	18,558	12,159
Buffalo Bayou	105	116	19,178	3,848
Cedar Bayou	211	153	6,686	151
Chocolate Bayou	170	95	4,703	80
Clear Creek	182	138	9,590	458
Dickinson Bayou	101	60	7,876	418
East Bay	288	193	6,983	4
Greens Bayou	209	184	15,003	4,157
North Bay	25	25	15,365	---
San Jacinto River	68	65	8,671	132
Ship Channel	166	198	16,157	1,494
Sims Bayou	93	91	15,039	627
South Bay	78	68	13,691	---
Trinity Bay	317	225	4,475	7
Trinity River	1,099	572	3,833	45
West Bay	344	212	8,081	7
White Oak Bayou	110	128	18,332	---

*Source: Table 7.1b (GSI, 1992)
**Geometric average of quadrilaterals from Table 5-2

mean of the Brays Bayou data is 12,159 FC/dL while the calculated mean from runoff data is 18,588 FC/dL. Buffalo and Greens bayous appear at least qualitativly similar. However, when comparing the open bay areas such as East, West or Trinity bays, there is no relation whatsoever. For example, East Bay's input based value is 6,983 FC/dL while its actual long-term geometric mean is 4 FC/dL. Clearly, a simple quantification of inputs sheds little light on the actual FC concentrations that will be experienced in the bay itself. However, quantification of factors such as source dynamics, die off rates (a function of light intensity, substrate concentration, etc.) and mixing processes is well beyond the scope of this project.